

Island wake impact on evaporation duct height and sea clutter in the lee of Kauai*

Lee J. Wagner, L. Ted Rogers

Space and Naval Warfare Systems Center, Code D858
San Diego, CA 92152-7385

Steve D. Burk, Tracy Haack

Naval Research Laboratory
Monterey, CA 93943-5502

Abstract - Perturbed flow over and around an island can produce leeside vortices and a long wake region of reduced wind speed and altered thermodynamic structure that impacts the evaporation duct height field and directional wave spectra, both of which impact radar sea clutter returns. In this paper, predicted radar clutter is constructed by using evaporation duct height and wind fields from a mesoscale model along with appropriate sea clutter and electromagnetic propagation models. This predicted radar clutter is compared to shipboard observations of radar clutter taken off the leeward side of Kauai, in December 1999.

INTRODUCTION

In December of 1999, shipboard observation of radar sea clutter were obtained in the lee of Kauai, HI aboard a U.S. Navy destroyer, the USS O’Kane. The O’Kane was equipped with Lockheed-Martin’s TEP (Tactical Environmental Processor). TEP extracts NEXRAD-like weather information from the AN/SPY-1 radar. Substantial azimuthal variability in the radar sea clutter was observed and postulated to result from an island wake. To test this hypothesis, the Naval Research Laboratory’s Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) was run to: (a) examine COAMPS ability to forecast an island wake and its impact upon the wind, thermodynamic, and evaporation duct fields, and (b) investigate the feasibility of assimilating COAMPS forecast fields and radar observations to optimally infer structural refractivity features.

*The analysis presented in this paper was funded under the Remote Refractivity Sensing project that is funded by Code 321 of the Office of Naval Research (ONR). The experimental work was funded by ONR Code 322.

COAMPS FIELDS

The COAMPS model was run with an inner nest horizontal grid interval of 3 km by 3 km using a Louis surface flux parameterization [1]. The domain of the inner nest ran from 20.946° to 23.196° North and 158.46° to 162.51° West, corresponding to a rectangular grid of 270 km by 450 km surrounding the island of Kauai. Fields obtained from the model included evaporation duct height (δ), wind velocity (v_w) and wind direction (θ). The three contour fields are shown in Figure 1 through Figure 3. The black cross in each figure represents the position of the USS O’Kane (22.03N, 159.92W) at 0511 (UTC) on December 3, 1999 and the fields correspond to a forecast time of 0600 (UTC). It can be seen that the O’Kane is in the wake predicted by COAMPS.

Looking at Figure 1 and Figure 2, there is a particularly inhomogeneous region of evaporation duct heights and wind speeds surrounding the O’Kane’s position. The

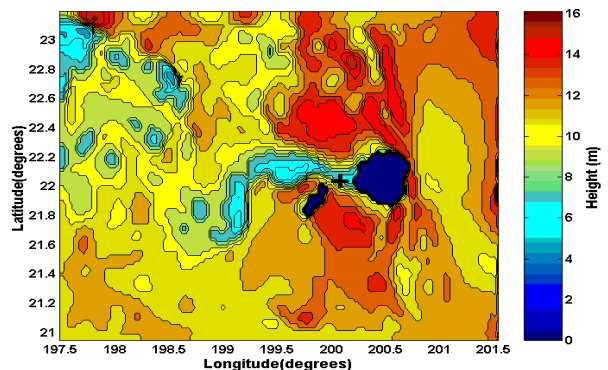


Figure 1: Contour plot of COAMPS evaporation duct height field.

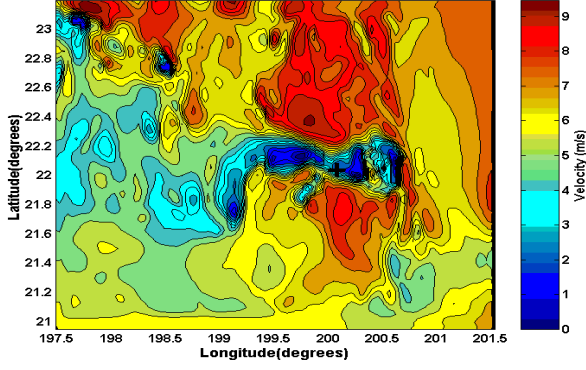


Figure 2: Contour plot of COAMPS wind velocity field.

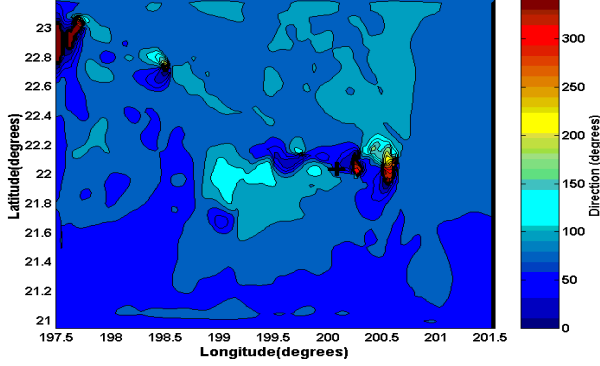


Figure 3: Contour plot of COAMPS wind direction field.

evaporation duct heights vary from 0 to 16 meters and the wind speeds vary from 0 to 10 m/s depending on the azimuth. The evaporation duct height is found to be higher in the high wind regions flanking the island and in the shear zones laterally bounding the wake, while duct heights in the wake itself are reduced from upstream values, thereby yielding pronounced inhomogeneity in the duct height field leeward of the island. The wind direction was out of the east, therefore causing the wind to be going over and around Kauai (Figure 3).

MODELED SEA CLUTTER POWER

The radar equation of Barton [2] can be manipulated to obtain the modeled radar clutter power $P_{c_{model}}$ in dBs, from the sea surface at range r to give

$$P_{c_{model}}(r) = A_c(r) - 2L(r) + \sigma^\circ(r) + offset \quad (1)$$

where A_c is the area illuminated by the radar, L is the propagation loss obtained from an electromagnetic propagation model, and σ° is the normalized radar cross section. An *offset* is then added to $P_{c_{model}}(r)$ which references the clutter power from range r_o from the ob-

served and modeled clutter power to give

$$offset = P_{c_{obs}}(r_o) - P_{c_{model}}(r_o) \quad (2)$$

where $P_{c_{obs}}(r_o)$ is the average observed clutter power at r_o and $P_{c_{model}}(r_o)$ is the average modeled clutter power at r_o both taken over 360 degrees. The modeled clutter power was generated in the following manner.

1. The range dependent evaporation duct heights (δ), wind speeds (v_w) and wind directions (θ) are collected from the COAMPS fields by circling the O'Kane's position in steps of 1.5° . The (δ) are used to generate neutral evaporation duct refractivity profiles by using the formula

$$M(z, \delta) = 0.13z - 0.13\delta(\ln(z/z_o)). \quad (3)$$

In this equation, $M(z, \delta)$ is the modified refractivity with respect to δ and z (the altitude above the sea surface), while z_o is a roughness factor whose typical over-water value is 1.5×10^{-4} [3].

2. The range dependent refractivity profiles and wind speeds along with certain parameters of the SPY-1 radar (frequency, beamwidth, antenna height, etc.) are input into the Advanced Propagation Model (APM) [4] to generate values of propagation loss L and grazing angle ψ at a height of 1.0 m over a range of 1-200 km.
3. The Georgia Institute of Technology (GIT) sea clutter model is used to compute σ° . The GIT σ° is a function of radar wavelength (λ), ψ , θ , v_w and average wave height (h_{av}) [5]. Since the h_{av} formula in the GIT model is based on a fully-developed sea, – a poor assumption in the lee of Kauai – a constant wave height was assumed. The constant h_{av} was calculated by finding the average wind speed on each azimuthal step of 1.5° . These wind speeds were then averaged over the entire 360° and this average wind speed was then input into the h_{av} formula in the GIT model.

RESULTS

The observed thresholded clutter map taken aboard the USS O'Kane is shown in Figure 4. The modeled clutter map generated from the COAMPS fields is shown in Figure 5 with the red lines representing the range the observed clutter power extended compared to the modeled clutter ranges for each 10° sector. Qualitatively, the modeled map displays much of the same features as the observed clutter map. They both have clutter

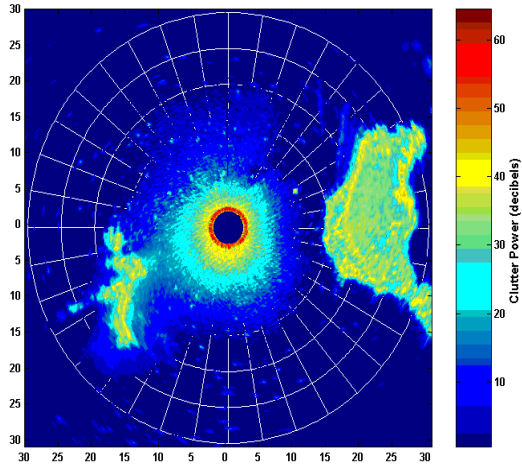


Figure 4: Observed AN/SPY-1 30km Clutter Map

power extending further out in range in the northerly and southerly directions from center. This appears to coincide with the higher wind speed and evaporation duct heights that were seen in Figures 1 and 2. Looking toward the island of Kauai, (90° radial) and the island of Niihau, ($250\text{-}260^\circ$ radials) the clutter falls off much more rapidly which would indicate lower evaporation duct heights and wind speeds as figures 1 and 2 show. The RMS difference between the model-predicted and median-filtered, observed clutter is ~ 1.5 dB.

SUMMARY

This demonstrates an instance where the outputs from the COAMPS model can be mapped into the space of the radar observations with (at least) visually appealing results. Mapping from the space of the model to the space of the observations (or vice versa) is a necessary step in fusing data from the model with that from the radar. Our future efforts will include: (a) bringing in h_{av} values from a wave model, (b) using a more rigorous modeling of the evaporation duct (i.e., using stability-dependent profiles rather than the neutral profile), and (c) examining a broad range of cases.

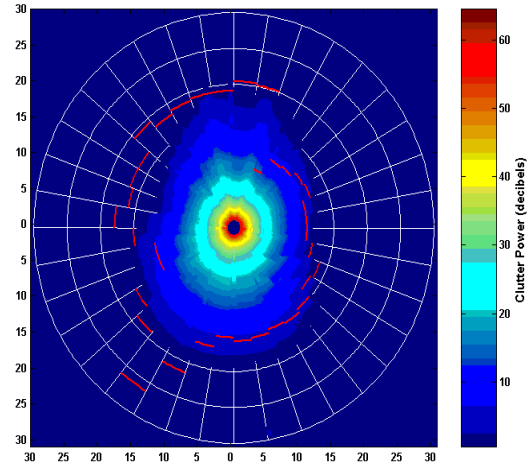


Figure 5: Modeled COAMPS 30 km Clutter Map

REFERENCES

- [1] Louis, J.F., 1979: A Parametric Model of Vertical Eddy Fluxes in the Atmosphere, *Bound-Layer Meteor.*, 17, 187-202.
- [2] Barton, D.K., *Modern Radar Systems Analysis*, Artech House, Norwood, Mass., 1988.
- [3] Gossard, E.E., and R.G. Strauch, *Radar Observations of Clear Air and Clouds*, Elsevier Sci., New York, 1983.
- [4] Barrios, A.E., A Terrain Parabolic Equation Model for Propagation in the Troposphere, *IEEE Trans. Antennas Propag.*, 42(1), 90-98, 1994.
- [5] Paulus, R.A., Evaporation Duct Effects on Sea Clutter, *IEEE Trans. Antennas Propag.*, 38(11), 1765-1771, 1990.
- [6] Rogers, L.T., C.P. Hattan, and J.K. Stapleton, Estimating Evaporation Duct Heights from Radar Sea Echo, *Radio Science*, 35(4), 955-966, 2000.